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OBSERVATIONS OF INTERFACE BEHAVIOR DURING INFLOW TO AN ELLIPTICAL ENDED CYLINDER IN WEIGHTLESSNESS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

An experimental investigation was conducted during which liquid was pumped into a 4-cm-diameter cylindrical tank, initially void of liquid, in a weightless environment. The tank bottom, an inverted ellipse, was scaled from the Centaur propellant tank, as was the inlet line location. Three inlet diameters (0.2, 0.4, and 0.8 cm) were studied. The liquid-vapor interface during inflow became increasingly distorted as inflow velocity was increased. Furthermore, any increase in the ratio of inlet diameter to tank diameter necessitates lowering of inlet velocity to maintain a stable liquid-vapor interface. All tests were conducted at the Lewis Research Center 2.2-second drop tower facility.

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ELLIPTICAL ENDED CYLINDER IN WEIGHTLESSNESS

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SUMMARY

An experimental investigation was conducted during which liquid was pumped into a 4-centimeter-diameter cylindrical tank, which was initially void of liquid, in a weightless environment. The tank bottom was an inverted ellipse and was scaled from the Centaur propellant tank, as was the inlet line location. Three inlet line diameters (0.2, 0.4, and 0.8 cm) were studied. Results indicate that the liquid-vapor interface configuration during inflow became increasingly distorted as the inflow velocity was increased. Furthermore, any increase in the ratio of inlet diameter to tank diameter necessitated a lowering of the inlet velocity in order to maintain a stable liquid-vapor interface.

INTRODUCTION

As a part of the overall study to determine the behavior of propellants and other liquids in space vehicle tanks while exposed to weightlessness, the Lewis Research Center is currently investigating some of the problems associated with liquid transfer in a zero-gravity environment. In order to select and design any transfer system, it is necessary to know the position and behavior of the liquid and vapor in both the receiver tank and the expulsion tank during the transfer operation. Much of the work to date has dealt with the outflow phenomena associated with the tanker vehicle and has demonstrated the importance of baffling the pressurant gas inlet and liquid outlet (ref. 1) to prevent premature ingestion of gas into the tank outlet. Results have been obtained which predict the distortion of the liquid-vapor interface during outflow (ref. 2) as a function of tank size, outflow velocity, and fluid properties.

The initial phase of the investigation of the inflow phenomena was conducted by Andracchio (ref. 3). The results of his study of baffled spherical tanks determine the range of inlet velocities over which a tank could be filled during weightlessness without

destabilizing the interface configuration. Subsequent work (ref. 4) has determined the relation of the variables of inflow velocity, tank size, and fluid properties during inflow for a cylindrical tank with hemispherical ends. The results indicated that a Weber number criterion (the ratio of inertia to capillary forces) is suitable for determining the stability limits of the liquid-vapor interface during inflow to a tank which is initially void of liquid.

Another tank shape currently in use is the cylindrical tank with an inverted elliptically shaped bulkhead at the lower end of the tank. This tank bottom shape represents a significant difference in the geometric surfaces which the liquid contacts as it enters the tank, as compared with the hemispherical bottom shape studied in reference 4. This report presents the results of a photographic study of the behavior of the liquid-vapor interface during inflow to an elliptically ended cylinder during weightlessness. In all tests, the tank was initially void of liquid. The general behavior of the liquid-vapor interface as affected by inlet line velocity and inlet size is discussed. The study, conducted in the Lewis Research Center 2.2-second drop tower facility, was limited to one test liquid (ethanol), one tank diameter (4 cm), and three inlet diameters (0.2, 0.4, and 0.8 cm).

APPARATUS AND PROCEDURE

Test Facility

The experimental tests were conducted in the drop tower shown in figure 1. The free-fall distance of 24 meters allowed a 2.2-second period of weightless test time. Effects of air drag on the experiment were maintained below 10^{-5} g by allowing the experiment to fall inside an air drag shield. During the drop, the package and drag shield fell simultaneously but were independent of each other. At the conclusion of the drop, the package was decelerated by impingement of the drag shield spikes in a bed of sand.

Experiment Package

The experiment tank was mounted in the experiment package shown in figure 2 and was illuminated so that the inflow phenomena could be recorded with a 16-millimeter motion picture camera. Electrical power, consisting of rechargeable nickel-cadmium batteries, was carried on the experiment package. A graduated glass cylinder, serving as the ethanol supply reservoir, was connected to the experiment tank inlet line with stainless-steel tubing. Positioned in the transfer line were a micrometering valve to
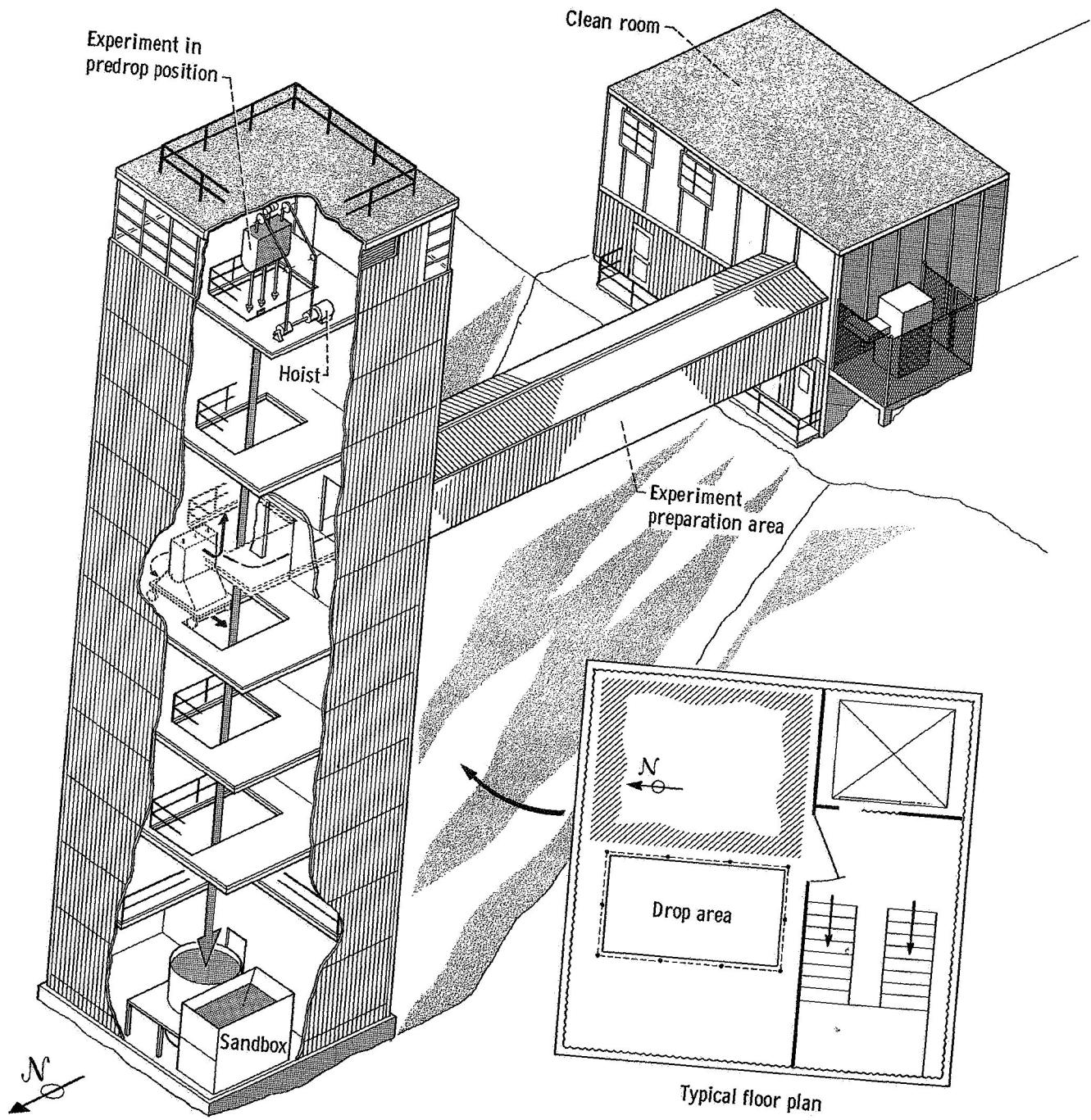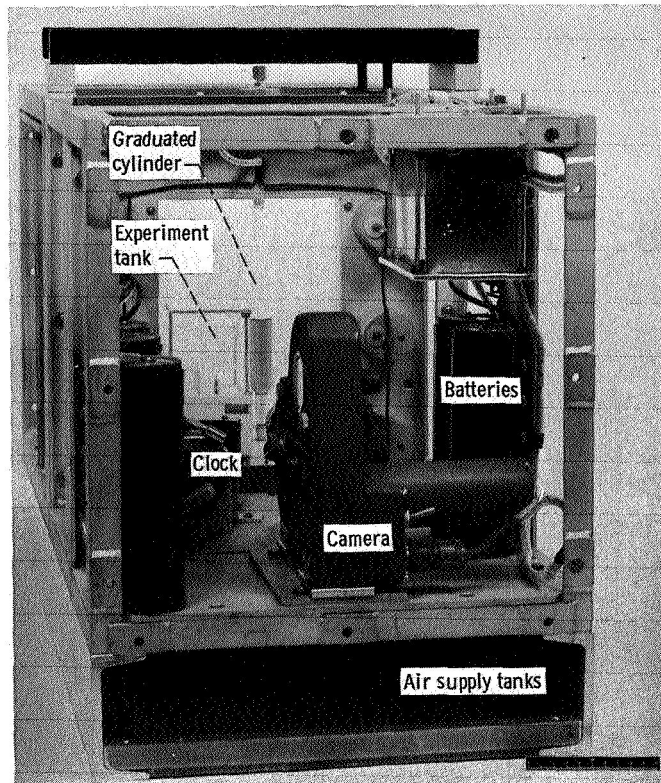
Experiment in predrop position

Clean room

Hoist

Experiment preparation area

N

N

Drop area

Typical floor plan

Sandbox

Figure 1. - Drop tower facility.

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C-67-655

Figure 2. - Experiment package.

regulate the flow rate and a solenoid valve to open and close the line.

Pressurized air, supplied to the top of the graduated cylinder through stainless-steel tubing, was contained in two pressure supply tanks having a total volume of 2000 cubic centimeters. This volume was large relative to the amount of liquid transferred (100 to 1) from the graduated cylinder to the experiment tank, and resulted in a negligible pressure drop during liquid transfer.

Experiment Tank and Test Liquid

The model tank used in this investigation was a cylinder machined from cast acrylic rod and polished for photographic purposes. The tank had an inside diameter of 4 centimeters and a length of 8 centimeters. The top was a hemisphere, while the bottom was an inverted ellipse (see fig. 3). The elliptical bottom section and the inlet line location were scaled from the Centaur propellant tank. The inlet line diameters of 0.2, 0.4, and 0.8 centimeter had a length equal to 10 times their diameter.
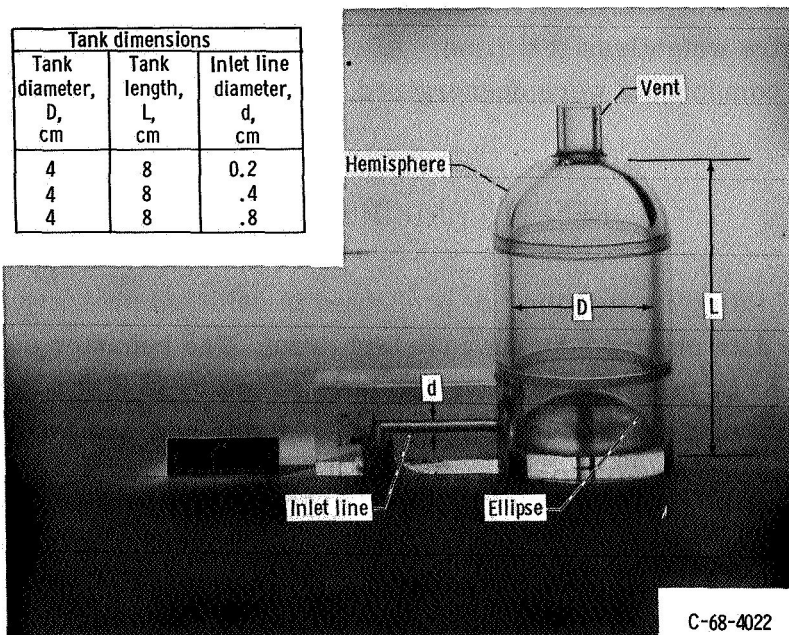
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Tank dimensions		
Tank diameter, D, cm	Tank length, L, cm	Inlet line diameter, d, cm
4	8	0.2
4	8	.4
4	8	.8

Figure 3. - Test tank details.

The **purity-certified** liquid used in this investigation was 200-proof ethanol. Approximately 1/2 liter was prepared for each test by adding methylene blue dye and then filtering the dyed liquid. The small amount of dye added improved the photographic quality of the liquid, but had no measurable effect on the physical properties of the ethanol.

Operating Procedure

Prior to assembling the experiment tank in the drop package, the tank and associated hardware were washed in detergent and water and then thoroughly cleaned in an ultrasonic cleaner. The parts were then rinsed with distilled water and dried in a warm-air dryer.

After installing the experiment tank in the package, the graduated cylinder was filled with the test liquid. The system was sealed and pressurized, and the metering valve was adjusted for the desired flow rate.

The camera was loaded, and the experiment package was balanced about the horizontal axes. The package was then placed in the air drag shield, and the entire assembly was hoisted to the predrop position on the eighth floor. The assembly was suspended by music wire attached to the experiment package. The music wire was notched by a knife edge which caused the wire to fail and permitted the package to enter free fall.

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The solenoid valve in the ethanol transfer line was actuated at the time the package entered free fall, allowing inflow to the experiment tank. The camera recorded the test results for the entire weightless test time. After impact in the sandbox at the end of the test all electrical components were deenergized.

RESULTS AND DISCUSSION

The results of this investigation are presented in selected photographs taken from the motion picture data obtained during each test drop. The behavior of the liquid-vapor interface as affected by inlet line velocity and tank geometry is discussed. In examining the photographs note that the tank is initially void of liquid and that inflow began when the package entered weightlessness (time = 0).

Effect of Inlet Line Velocity

In order to determine the gross effect of inlet velocity on the liquid-vapor interface during inflow, a series of tests was conducted in which a range of inlet velocities was used to transfer liquid into a 4-centimeter-diameter tank having a 0.4-centimeter inlet line diameter.

The liquid-vapor interface configuration at the relatively low inlet velocity of 14.7 centimeters per second is shown in figure 4(a). Note that, shortly after the initiation of inflow (time, 0.65 sec), the liquid enters the tank and begins to accumulate between the tank wall and the elliptical tank bottom near the tank inlet. As inflow continues (time, 1.15 sec), the liquid spreads around the elliptical bottom and reaches the tank wall opposite the inlet line. The liquid-vapor interface then becomes approximately symmetrical about the longitudinal axis of the tank (time, 2.10 sec) and appears to maintain this essentially stable configuration.

In figures 4(b) and (c) the interface configuration at inlet velocities of 22.5 and 29.7 centimeters per second, respectively, are shown. In both tests, shortly after the initiation of inflow, the liquid again begins to accumulate between the tank wall and the elliptical bottom near the tank inlet (time, 0.45 sec); however, as inflow continues (fig. 4(b), time, 1.10 sec; fig. 4(c), time, 1.15 sec), the liquid wets over and around the elliptical bottom. Note that in figure 4(b), time, 1.10 sec, the interface is relatively undistorted; however, at nearly the same time in figure 4(c), an excess of liquid is located at the tank wall opposite the inlet line. Near the end of the available test time (fig. 4(b), time, 2.15 sec; fig. 4(c), time, 2.07 sec), the interface is distorted from its stable configuration (symmetrical about the longitudinal axis of the tank). The liquid-vapor interface

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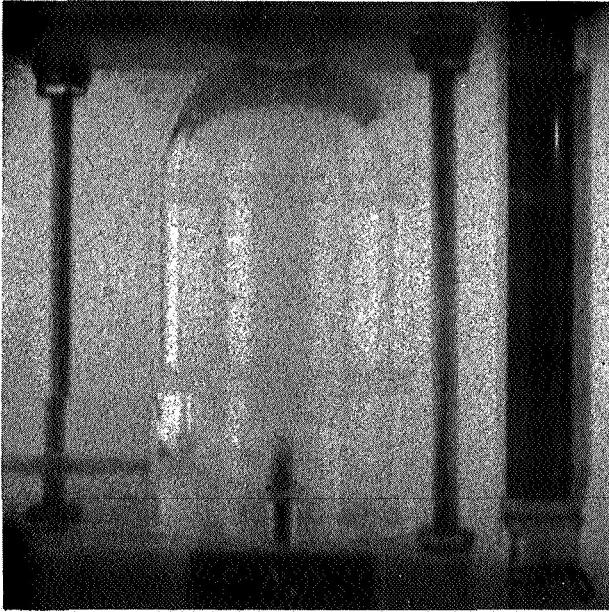
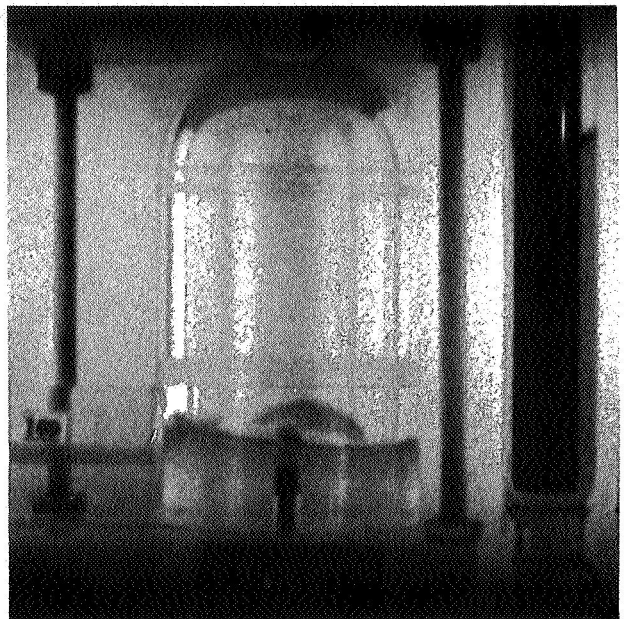Time, 0.65 second.

Time, 1.15 seconds.

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Time, 2.10 seconds.

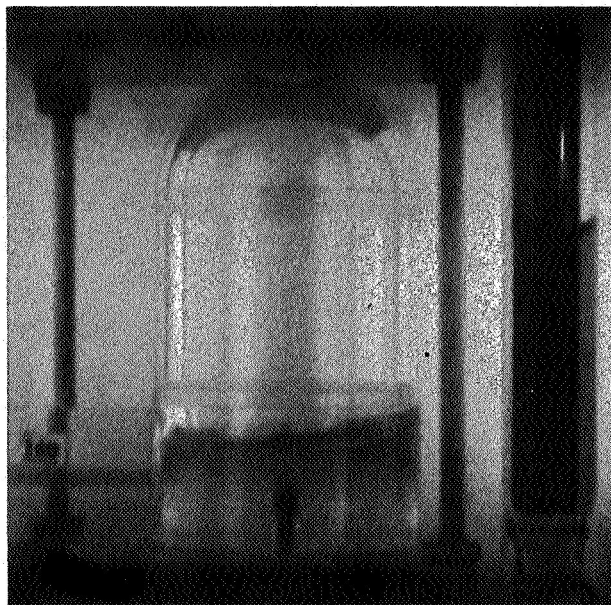(a) Inlet velocity, 14.7 centimeters per second.

Figure 4. - Interface configuration during inflow at various inlet velocities. Tank diameter, 4 centimeters; inlet diameter, 0.4 centimeter.

Time, 0.45 second.

Time, 1.10 seconds.

C-68-3385

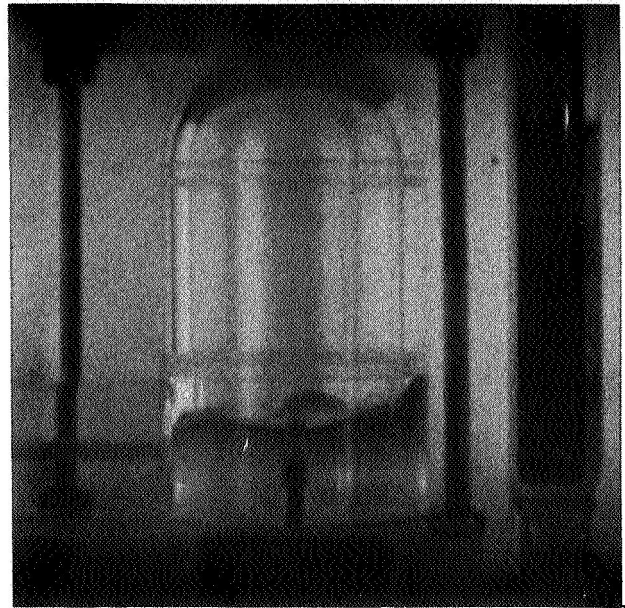Time, 2.15 seconds.

(b) Inlet velocity, 22.5 centimeters per second.

Figure 4. – Continued.

Time, 0.45 second.

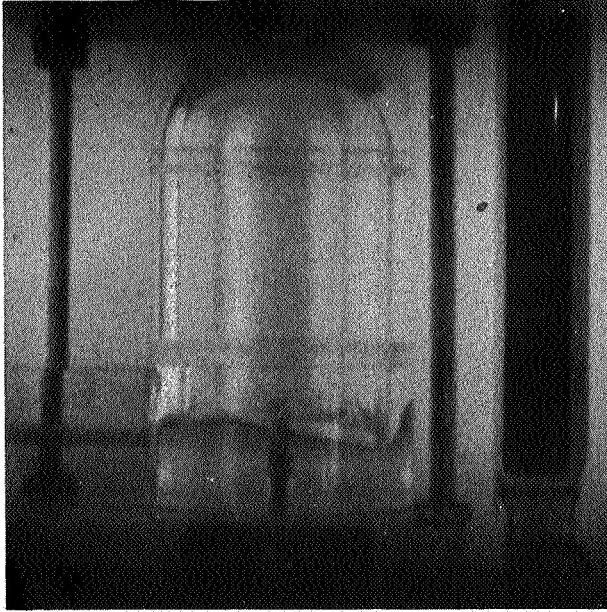Time, 1.15 seconds.

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Time, 2.07 seconds.

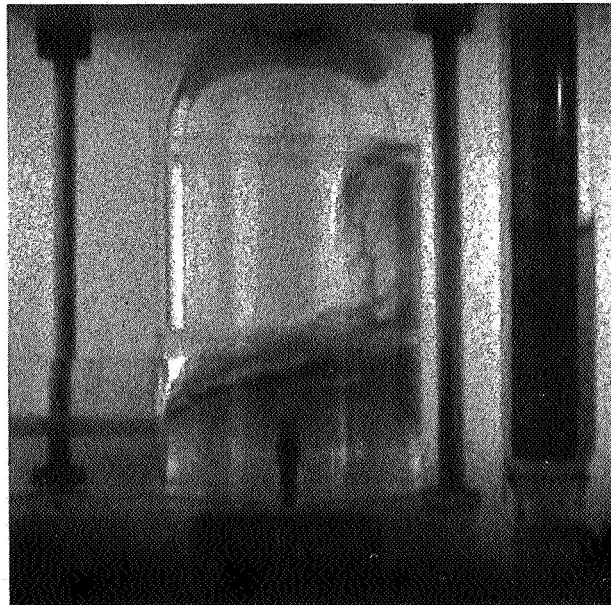(c) Inlet velocity, 29.7 centimeters per second.

Figure 4. - Continued.
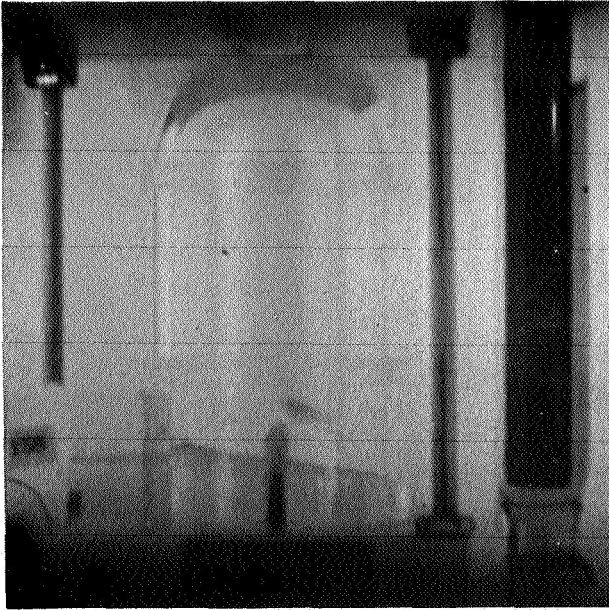
Time, 0.45 second.

Time, 1.15 seconds.

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Time, 2.15 seconds.
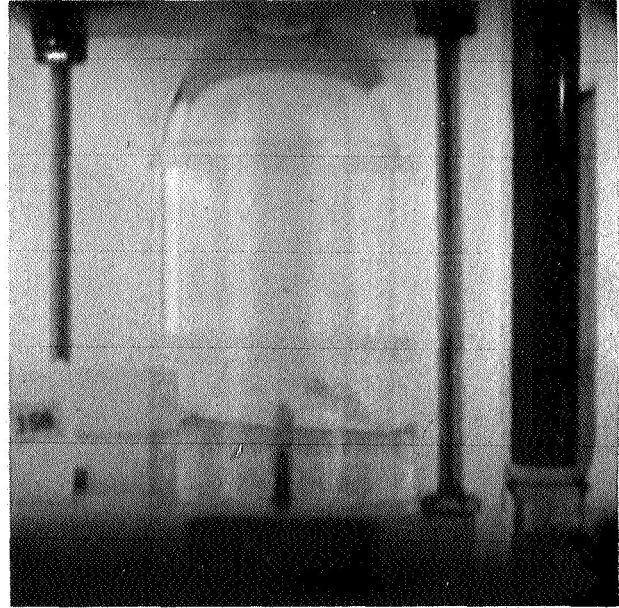
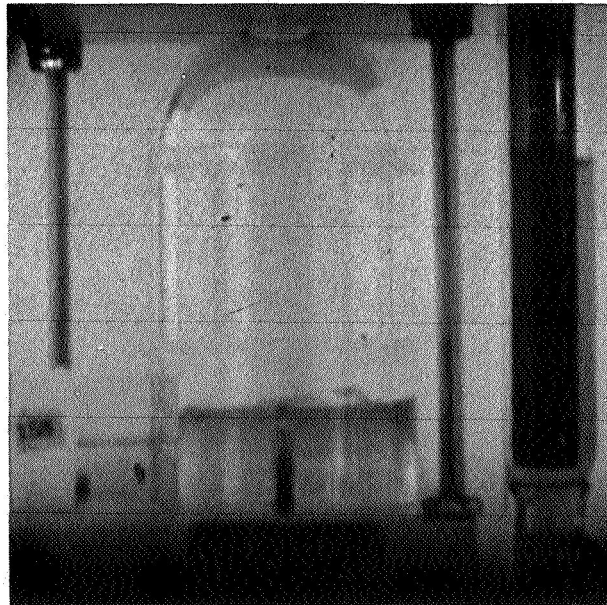(d) Inlet velocity, 41.5 centimeters per second.

Figure 4. - Concluded.

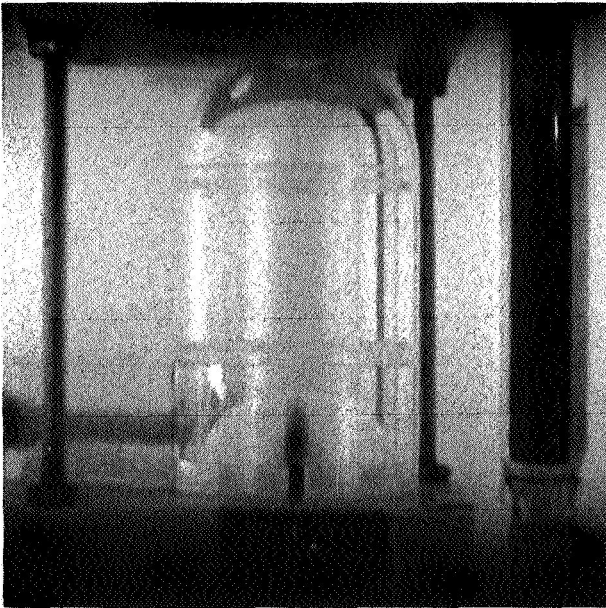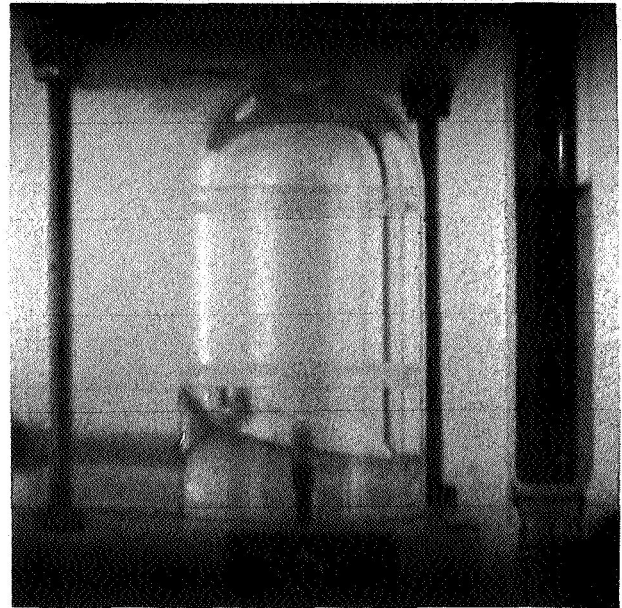10

Time, 0.65 second.

Time, 1.15 seconds.

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Time, 2.15 seconds.

(a) Inlet velocity, 67.5 centimeters per second; inlet diameter, 0.2 centimeter.
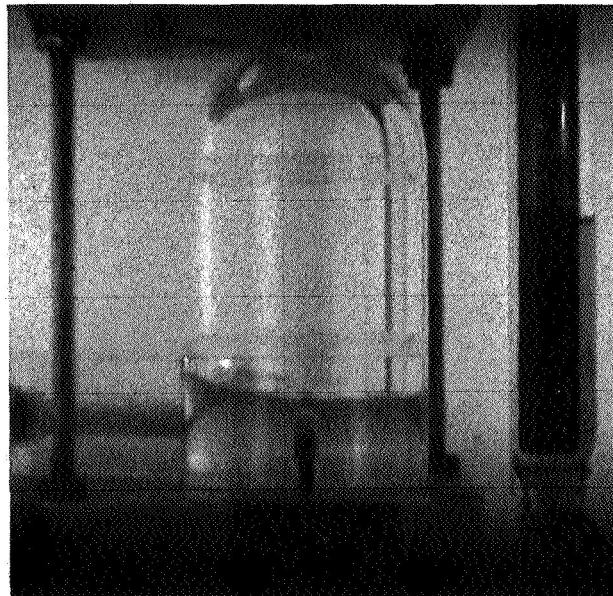
Figure 5. - Stable liquid-vapor interface configuration during inflow at two inlet velocities and two inlet diameters. Tank diameter, 4 centimeters.

Time, 1.10 seconds.   Time, 1.65 seconds.

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Time, 2.15 seconds.

(b) Inlet velocity, 7.9 centimeters per second; inlet diamter, 0.8 centimeter.

Figure 5. - Concluded.

which assumes the configuration shown in figures 4(b) and (c) is termed a stable, but distorted, interface.

Increasing the inlet velocity to 41.5 centimeters per second causes the interface to become unstable, as evidenced by the sequence of figure 4(d). Shortly after the initiation of inflow (time, 0.45 sec), the liquid has wet completely over and around the elliptical bottom and has started to rise up the tank wall opposite the inlet line. It is an interesting point that, even at this relatively high inlet velocity, the incoming liquid wet the elliptical bottom rather than rebounding off it in spraylike fashion. Continuing inflow (time, 1.15 sec) causes the liquid to rise further up the wall. At the same time, relatively little liquid is being retained near the inlet line. Near the end of the available test time (time, 2.15 sec), the incoming liquid has risen up the tank wall opposite the inlet line and is approaching the vent. This particular type of interface is termed unstable since any further inflow would result in the incoming liquid being pumped over and around the elliptical bottom, up the tank wall opposite the inlet line, and out the vent, permitting liquid to escape before an appreciable volume had entered the tank.

Effect of Tank Inlet Geometry

An additional series of tests was conducted in order to determine the effect of the ratio of inlet line diameter to tank diameter on the stability of the liquid-vapor interface during inflow. In these tests, the tank diameter was maintained at 4 centimeters, as in the previous tests, but the inlet line diameter was varied. Selected frames from these tests are shown in figures 5(a) and (b). The inlet velocity in each of these tests was the highest velocity which still maintained the liquid-vapor interface in its stable configuration for that tank inlet geometry. The inflow process at a velocity of 67.5 centimeters per second in a tank with a 0.2-centimeter inlet diameter (inlet- to tank-diameter ratio, 1/20) is shown in figure 5(a), while figure 5(b) shows inflow at a velocity of 7.9 centimeters per second in a tank with a 0.8-centimeter inlet diameter (inlet- to tank-diameter ratio, 1/5). The observed interface behavior was essentially the same in both of these tests, and similar to the stable configuration shown in figure 4(a). Initially, the liquid entered the tank and began to accumulate between the elliptical bottom and the tank wall near the inlet line (fig. 5(a), time, 0.65 sec; fig. 5(b), time, 1.10 sec). As inflow continued (fig. 5(a), time, 1.15 sec; fig. 5(b), time, 1.65 sec), the liquid wet over and around the tank bottom and reached the tank wall opposite the inlet line. Near the end of the available test time (time, 2.15 sec), the interface had become approximately sym-

metrical about the longitudinal axis of each tank.

It is evident from these figures that an increase in the ratio of inlet line diameter to tank diameter necessitates a lowering of the inlet velocity in order to maintain stability of the liquid-vapor interface. Furthermore, it is again significant that at the relatively high inlet velocity of 67.5 centimeters per second, no rebounding of the incoming liquid off the elliptical bottom was observed.

SUMMARY OF RESULTS

This investigation determined the liquid-vapor interface behavior when liquid was pumped into a cylindrical tank with an inverted elliptical lower end during weightlessness. The tank was initially void of liquid. The following results were obtained:

1. Three liquid-vapor interface configurations were observed during the inflow process:

    a. A stable liquid-vapor interface configuration in which the liquid appeared to uniformly wet the elliptical tank bottom and then move symmetrically up the tank walls

    b. A stable but distorted liquid-vapor interface configuration in which the incoming liquid moved over the elliptical bottom and appeared to accumulate on the wall of the tank opposite the inlet line

    c. An unstable liquid-vapor interface configuration in which the liquid wet the elliptical bottom and then moved up the tank wall opposite the inlet line

2. As the velocity in a given inlet line was increased, the distortion of the liquid-vapor interface correspondingly increased.

3. An increase in the ratio of inlet line diameter to tank diameter from 1/20 to 1/5 required the inlet velocity be lowered from 67.5 to 7.9 centimeters per second in order to maintain stability (condition b above) of the liquid-vapor interface.

4. For the highest inlet velocities investigated, the incoming liquid always wet the ellipse and never rebounded off the ellipse in spraylike fashion.

Lewis Research Center,
    National Aeronautics and Space Administration,
        Cleveland, Ohio, September 25, 1968,
            124-09-17-01-22.

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— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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